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Host plant specificity and potential impact of *Aceria salsolae* (Acari: Eriophyidae), an agent proposed for biological control of Russian thistle (*Salsola tragus*)

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Abstract

Russian thistle (common tumbleweed), *Salsola tragus* (Chenopodiaceae), is an alien weed that is widespread in the western United States. A population of the eriophyid mite, *Aceria salsolae* (Acari: Eriophyidae), was collected in Greece and evaluated for host plant specificity as a prospective biological control agent. The mite usually does not form galls, but is a vagrant that usually inhabits the crevices of leaf and flower buds. Feeding damage causes meristematic tissue to die, which stunts the plant. The mite was able to multiply only on species in the *Salsola* section *Kali* subsection *Kali*, which includes the alien weeds *Salsola collina*, *Salsola kali*, and *Salsola paulsenii*. It did not damage or multiply on *Salsola soda*, which is in a different section, nor on *Halogeton glomeratus*, which is in the same tribe. The mite reduced the size of Russian thistle plants by 66% at 25 weeks post-infestation under artificial conditions. The results indicate that the mite poses negligible risk to nontarget native North American plants or economic plants, and it may substantially reduce the size of Russian thistle plants and their population density.
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Keywords: Tumbleweed; Mite; Biological control of weeds; Host range; Classical biological control

1. Introduction

1.1. Weed distribution and impact

Russian thistle, *Salsola tragus* L. (*sensu lato*) (Chenopodiaceae), is a weedy annual tumbleweed that infests about 41 million hectares in the western United States (Prather, 1995; Young, 1991). It is native to the mountainous regions of southwest Asia, but is now distributed across Eurasia between 25° and 60°N latitude (Botschantzev, 1969; Rilke, 1999). The plant is also established as an alien weed in Argentina, Chile, Canada, Mexico, South Africa, Indonesia, Japan, Australia, New Zealand and the United States (Crompton and Bassett, 1985; Holm et al., 1977; Young, 1991). In North America, it was first introduced accidentally in the early 1870s in South Dakota (Crompton and Bassett, 1985). Since then, it has spread over most of the central and western United States and southern Canada. It grows primarily in fallow or disturbed soil, along roadsides and irrigation canals, and in waste areas in arid and semiarid zones.

Russian thistle is listed as a noxious weed in five states and six Canadian provinces (Skinner et al., 2000). Russian thistle causes problems and millions of dollars of losses in a variety of ways. (1) Tumbling plants disrupt automobile traffic, clog irrigation canals and pile up against fences and houses (Goeden and Ricker, 1968). The California Department of Transportation applies control efforts against Russian thistle along the major highways costing approximately $1.2 million

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dollars annually (R. Johnson, CalTrans Landscape Supervisor, personal communication). (2) It is a major weed in fallow dryland farming, especially in spring wheat and reduced tillage management (Schillinger and Young, 2000; Young et al., 1995). (3) It harbors and increases populations of important insect pests of many fruits and vegetables, including the beet leafhopper (*Circulifer tenellus* (Baker)), Say's stinkbug (*Pitedia sayi* (Stal)), and lygus bug (*Lygus hesperus* Knight) (Goeden, 1968). The beet leafhopper transmits curly top virus, an extremely serious gemini virus infecting several hundred varieties of ornamental and commercial crops, including sugarbeets, tomatoes, melons, cucumbers, peppers, squash, spinach, and beans (Bennett, 1971; Douglas and Cook, 1953; Douglas et al., 1955). California Department of Food and Agriculture (CDFA) applies insecticides to Russian thistle in an abatement program to control these insects, costing approximately $1.2 million per year (M. Pitcairn, CDFA, personal communication). (4) Dry plants of Russian thistle are highly flammable, and tumbling plants can rapidly spread wildfires. (5) The pollen is a human allergen and is widely dispersed by wind (Al-Dowaisan et al., 2004; Bassett et al., 1978; Gadermaier et al., 2004). (6) During drought periods, Russian thistle can invade some habitats and displace native species (Allen, 1982; Brandt and Rickard, 1994).

1.2. Weed management options

Herbicides are used to control Russian thistle on cropland, roadsides and rights of way, but they are not economical to apply on open rangeland (Cudney et al., 2004; Young et al., 1995). Herbicides can cause environmental contamination and affect nontarget species. Russian thistle has developed resistance to at least one class of herbicides, the sulfonylureas, which makes it more difficult to control (Peterson, 1999; Saari et al., 1992; Stallings et al., 1994; Young et al., 1995). About 70% of the sites infested with Russian thistle in eastern Washington now contain plants that are resistant to sulfonylurea herbicides, and resistance has been reported in California, Oregon, Montana, and Idaho. In dryland agricultural areas, tilling fallow fields to control Russian thistle produces dust and contributes to air pollution (Schillinger and Young, 2004). In California's Great Central Valley, poor air quality has become a major problem and public opposition to such tillage is increasing. The insect species that feed on Russian thistle in the US do not significantly reduce its abundance (Goeden and Ricker, 1968). Russian thistle generally appears to not compete well with established vegetation; so, establishing competing vegetation may be an effective strategy, where appropriate. Fire has generally not been used as a management tool for this weed.

1.3. Plant taxonomy

Identification of Russian thistle is difficult because of high morphological variability and similarity to closely related species in the genus and the occurrence of hybrids and polyploids. The nomenclature of this species has changed over time, and 55 synonyms of *S. tragus* were listed in Rilke's (1999) recent revision of the section *Salsola sensu lato* of the genus *Salsola*. Common misnomers or synonyms in recent scientific literature include, *Salsola australis* R. Brown, *Salsola iberica* Sennen and Pau, *Salsola kali* L., *S. kali* L. ssp. *tragus* (L.), *Salsola pestifer* Nelson, and *Salsola ruthenica* Iljin. Mosyakin (1996) reviewed the taxonomy and provided a key for members of the genus extant in North America. However, despite the taxonomic work of Rilke and Mosyakin, scientists often still use incorrect names (e.g., Harbour et al., 2003; Hasan et al., 2001; Khan et al., 2002; Schillinger and Young, 2004).

Recent isozyme and DNA evidence indicates that the species *S. tragus* has two genetic forms, called types A and B, both of which occur in California (Ryan and Ayres, 2000). Type A specimens from California are similar to *S. tragus* specimens found in Eurasia; however, no type B specimens have yet been found in Eurasia (F. Hrusa, CDFA, personal communication). Type A and B differ in their susceptibility to a host-specific fungal pathogen (*Colletotrichum gloeosporoides*) and a gall-forming midge (*Desertovellum stackelbergi* Mamaev) (Bruckart et al., 2004; Sobhian et al., 2003). Other forms of Russian thistle that occur in the US are currently designated "type C" and are suspected to be hybrids of type A, type B and/or forms of *Salsola paulsenii* Litv. (Arnold, 1972; Beatley, 1973; F. Hrusa, CDFA, personal communication). *S. paulsenii* has at least two genetic/morphological forms: "lax" and "spinose" (Arnold, 1972; Rilke, 1999; Ryan et al., 2000).

The genus *Salsola* consists of approximately 116 species worldwide (Kühn, 1993). Seven species of *Salsola*, all alien, are established in North America (Table 1; Mosyakin, 1996; USDA NRCS, 2001). Many of these species are listed as noxious at the state or federal level: *Salsola collina* Pallas in CA and CO; *S. kali* in CA, CO, HI, MN, OH, and five Canadian provinces; *S. paulsenii* in CA; and *Salsola vermiculata* s.l. (= *Salsola damascena* s.str.) in CA, FL, NC, and in the Federal Noxious Weed List. Note that the political agencies responsible for listing these species may have used the wrong scientific name for the weed they desire to control (e.g., "*S. kali*" for inland states and provinces probably represents *S. tragus*, *S. collina* and/or *S. paulsenii*). Because of this historical confusion, in this paper the phrase "*S. tragus* (*sensu lato*)" will be used to include the weedy species *S. tragus* (types A and B), *S. collina*, *S. kali*, *S. paulsenii* and any of their hybrids, all of which are in the *Salsola* section *Kali* subsection *Kali* (Rilke, 1999).

Table 1
Species (all alien) of the genus *Salsola* established in North America (Mosyakin, 1996)

Scientific name	Common name[a]	Distribution[b]
Salsola collina Pallas	Slender Russian thistle	Waste places, roadsides, cultivated fields: 2 Can; MI to OK to AZ to ND
Salsola kali L. ssp. *kali*	Russian thistle	Seashores: e Canada to SC
Salsola kali L. ssp. *pontica* (Pallas) Mosyakin	Russian thistle	Seashores: MA to FL to TX; OR to CA; Mexico
Salsola paulsenii Litv.	Barbwire Russian thistle	Open sandy soil: AZ, CA, CO, NV, UT
Salsola soda L.	Opposite leaf Russian thistle	Seashores: CA
Salsola tragus L.	Prickly Russian thistle	Waste places, roadsides, cultivated fields: 48 US states; 10 Can; Mexico
Salsola vermiculata L.	Shrubby Russian thistle	Rocky slopes, clay soils: CA

[a] *Source*. From PLANTS database (USDA, NRCS 2001); however, in this paper "Russian thistle" refers to *S. tragus*, and "*S. tragus* (*sensu lato*)" includes all the taxa except *S. soda*, which is in a different section (*Salsola*) of the genus from the others (*Kali*) (Rilke, 1999).
[b] US postal codes for states; Can, Canadian provinces.

The only species within the tribe Salsoleae that occur in North America are seven alien species of *Salsola* and the alien invasive weed, *Halogeton glomeratus* (Bieb.) C.A. Mey. Because *S. tragus* has no close taxonomic relatives (within the same genus or tribe) that are native to North America, there is a high likelihood of finding classical biological control agents that would not harm native or cultivated plant species.

1.4. Biological control

A biological control program for Russian thistle in the United States was initiated around 1970, which led to the introduction and establishment of two moths: *Coleophora parthenica* Meyrick (Lepidoptera: Coleophoridae), a stem borer, and *Coleophora klimeschiella* Toll, a defoliator (Goeden, 1973; Hawkes and Mayfield, 1976, 1978). However, these insects did not attain high population densities because of interference from their natural enemies and are not controlling the weed (Goeden and Pemberton, 1995; Muller et al., 1990; Nuessly and Goeden, 1983, 1984).

The mite, *Aceria salsolae* de Lillo and Sobhian (Acari: Eriophyidae) is considered to be the best available prospective agent (Sobhian, 2000). It is a recently discovered species, first described in 1996, that has been collected only from *S. tragus* (*sensu lato*) (de Lillo and Sobhian, 1996). It is known to occur in Turkey, Greece, and Uzbekistan, but is probably more widespread. Preliminary no-choice experiments showed that the mite could multiply on Turkish "*S. kali*" (possibly *S. kali* subsp. *pontica* or *S. tragus* based on the geographic origin: near Afyon Turkey) and Californian *S. tragus*, but not on spinach, table beet, Swiss chard, sugarbeet, common purslane (*Portulaca oleracea* L.), or common goosefoot (*Chenopodium* sp.) (Sobhian et al., 1999). Little is known about its life history. Only the protogyne stage has been described (de Lillo and Sobhian, 1996), although the mite probably has a dormant stage that persists through the winter and early spring, when the host plant is unavailable. Protogynes are multivoltine under laboratory conditions (described below). Development time, fecundity, and adult longevity have not been precisely measured, but they appear to be similar to those of other eriophyids that have been more intensively studied (Bergh, 1994); i.e., about 1 week from egg to adult, about 50 eggs per female, and about 3 weeks for adult female longevity at room temperature.

The purpose of this study was to evaluate the host range of this mite and its potential impact on the target plant to determine if it would be suitable for introduction as a classical biological control agent.

2. Materials and methods

2.1. Mite population

The population of the mite was collected at one location in northern Greece (500 m elevation, 40°16.41′N, 21°53.16′E) on *S. tragus* by J. Kashefi on 30 September 2001. The colony was established by individually transferring mites on an eyelash to fresh 15-cm cuttings of *S. tragus*. The colony has been maintained in quarantine on *S. tragus* cuttings, and each new generation of mites was transferred to fresh cuttings. Experiments were conducted during 2002–2004 inside the quarantine laboratory at the USDA-ARS Western Regional Research Center in a room specially designed to work with mites. Escape of mites was prevented by a combination of maintaining slightly "negative" air pressure in the room by an exhaust fan that pulled air through a HEPA filter. Mites were held in glass-topped wooden sleeveboxes for the laboratory colony and the impact experiment, and in Dacron chiffon screen cages (70 mesh; aperature 0.3 mm) for the no-choice host specificity experiments. Vaseline smeared around the outside of each flower pot provided a barrier against mite movement, and double-sided tape was placed on the floor around each flower pot to prevent mites from crawling away. The sleevebox and screen cage prevented air drafts which might permit the mites to disperse aerially (a normal means of dispersal (Bergh, 2001)). Working surfaces were regularly disinfested with 95% ethanol, and sentinel cuttings of *S. tragus* placed outside the cages were regularly monitored to detect possible escape of mites.

2.2. Host specificity

When the mite colony was first established, 15-cm cuttings of *S. tragus* types A, B, and C, and *S. paulsenii* lax and spinose forms were infested by placing a small cutting (ca. 4 cm) of *S. tragus* type A from the mite colony, each containing at least 40 mites of various developmental stages, to determine if these plants were acceptable. Mite populations were visually inspected after 4 weeks, but not counted, to determine if the mites could multiply on these plants. Similar cuttings of *S. tragus* used as sentinel plants to detect possible escape of mites in the same room have persisted in healthy condition for 3 months, so the use of cuttings was a practical alternative to using whole plants.

Following demonstration that the mite could attack all varieties of the target weed, a method to count mites on the plants was developed (see below). Host specificity of the mite was determined by use of no-choice tests, which is the most conservative approach (Hill, 1999). Cuttings of *S. tragus* type A containing about 40 mites (minimum of 20) of various developmental stages were transferred to individual potted test plants. As the cuttings dried, the mites moved onto the test plants. The infested cuttings had been exposed to mites for 3–4 weeks in a laboratory colony and had mites actively crawling toward the apex, which indicates that they were ready to disperse. All test plants were a minimum of 5 cm tall, and their age varied depending on how quickly they attained this size (mean: 7 weeks, range: 2–22 weeks). Test plants were free of other arthropod pests and were held in sleeve boxes or a fine mesh cage under a combination of fluorescent and halogen lamps (140 μmole/s PAR) with a 16 h diurnal photoperiod. The daily temperature oscillated between 19 and 34 °C.

After 4–5 weeks, the test plants were examined for signs of mite damage and for the presence of mites under a microscope at 20× magnification. Then the plants were cut up and washed in a soapy solution to extract all mites (de Lillo, 2001). This procedure was at least twice as effective for finding mites as visual inspection of intact plants. The extract solution was examined under the microscope and all mites were counted. For samples that had a large number of mites, a grid (5 mm × 5 mm cells) was placed under the petri dish and mites in seven diagonal cells were counted. This number was multiplied by the ratio of the area of the dish to that of the seven cells to estimate the population.

Some of the native plants were difficult to grow, and any that were dead or sickly from other causes were omitted from the results. Plants were fertilized biweekly and watered as needed. Nine different plants of each species and variety were tested whenever possible. Two cuttings of *S. tragus* type A (15 cm long) held in vials of tap water were infested the same way and at the same time as each batch of test plants to serve as “positive” controls. Mites were extracted and counted from these at the same time as the nontarget test plants. Such cuttings can last several months and have been routinely used to maintain our mite colony. They provided plant area similar to or smaller than that of the test plants.

The list of plants tested included 39 species from five families, including 25 native species and six economic species (15 varieties) (Table 2). Taxa were selected based on the phytocentric approach (Wapshere, 1974), focussing on species most closely related to the target weed (genus *Salsola*). There are no native North American plants in the same tribe (Salsoleae) as the target, but we tested *H. glomeratus*, which is a noxious weed. We tested several native species in two other tribes (Suaedeae and Sarcobateae) within the same subfamily (Salsoloideae). Within the Family Chenopodiaceae, there are three other subfamilies that include native North American plants: Chenopodioideae (in the genera: *Aphanisma*, *Chenopodium*, *Monolepis*, *Endolepis*, *Atriplex*, *Suckleya*, *Krascheninnikovia*, *Grayia*, *Zuckia*, *Cycloloma*, *Bassia* (including *Kochia*), and *Corispermum*); Salicornioideae (*Allenrolfea* and *Salicornia*); and Polycnemoideae (*Nitrophila*). Economic species occur in three tribes in the subfamily Chenopodioideae: Beteae (table beet, sugarbeet, Swiss chard), Chenopodieae (quinoa), and Atripliceae (spinach). The closest related family is Amaranthaceae (Kühn, 1993), and species in two subfamilies (Amaranthoideae and Gomphrenoideae) that contain economic and native species were tested.

2.3. Host impact

Salsola tragus type A plants were grown from seed in pots (4.5 L) with artificial soil (2 parts Supersoil: 1 perlite: 1 sand) in a greenhouse for 7 weeks. The plants were examined for arthropod pests, any of which were removed, before placing them in sleeveboxes inside the quarantine laboratory. Plant height ranged from 10 to 17 cm. Lighting was provided by 200 W halogen lamps (10:00–15:00 h) at 19 cm and two 32 W overhead fluorescent lamps (06:00–20:00 h) at 30 cm above top of sleevebox, which provided up to 140 μmol/s PAR. A yellow sticky card was used in each sleevebox to control fungus gnats. The temperature inside the sleeveboxes oscillated between 19 and 34 °C each day. The plants were infested with at least 40 mites by transferring cuttings of *S. tragus* that had been exposed in the mite colony for 3 weeks. Plants were fertilized biweekly and were watered as needed. On weeks 6, 12, and 25, 4-cm lengths of branch tips were cut, and mites were extracted and counted, as described above. At week 25, the combined length of all branches was measured. At week 37 the experiment was stopped because some of the control plants had become

Table 2
Infestation of test plants 4–5 weeks after transfer of about 40 mites

Plant species[a]	No. plant replicates	Plants infested (%)	No. mites per infested test plant	
			Test plant (±SE)	Positive control (±SE)
Family Chenopodiaceae				
Subfamily Chenopodioideae				
ATRIPLICEAE				
Atriplex canescens (Pursh) Nutt.[b]	8	0	0	67 ± 26
Atriplex confertifolia (Torr. & Frém.) S. Wats.[b]	10	0	0	124 ± 15
Atriplex elegans (Moq.) D. Dietr.[b]	15	0	0	126 ± 24
Atriplex truncata (Torr. ex S. Wats.) Gray[b]	9[c]	0	0	917 ± 134
Grayia spinosa (Hook.) Moq.[b]	13	0	0	247 ± 62
Kochia americana S. Watson[b]	9	0	0	798 ± 145
Kochia scoparia (L.) Schrad.	3	0	0	108 ± 57
Krascheninnikovia (= *Ceratoides*) *lanata* (Pursh) A.D.J. Meeuse & Smit[b]	9	0	0	224 ± 37
Spinacia oleracea L. (Spinach):				
Space (Bejo)	20	0	0	261 ± 61
Bolero	9	0	0	211 ± 73
Bossanova	9	0	0	291 ± 65
Clermont	9	0	0	149 ± 15
Spin	9	0	0	93 ± 21
Suckleya suckleyana (Torr.) Rydb.	10	0	0	565 ± 105
Zuckia (= *Grayia*) *brandegeei* (Gray) Welsh & Stutz ex Welsh	9	0	0	227 ± 62
BETEAE				
Beta vulgaris L.:				
Sugarbeet:				
Rifle, Spreckles/Holly	9	0	0	268 ± 72
Owyhee (Novartis)	9	0	0	829 ± 88
8757, Beta Seeds	9	0	0	98 ± 46
NB7R	9	0	0	93 ± 21
Table beet:				
Red Ace Hybrid	9	0	0	134 ± 52
Swiss chard:				
Lucullus	9	0	0	62 ± 21
Rhubarb	9	0	0	167 ± 38
CHENOPODIEAE				
Chenopodium ambrosioides L.	9	0	0	299 ± 72
Chenopodium berlandieri Moq.[b]	9	0	0	263 ± 5
Chenopodium fremontii S. Wats.[b]	9	0	0	247 ± 52
Chenopodium quinoa Willd.	9	0	0	252 ± 57
Monolepis nuttalliana (J.A. Schultes) Greene[b]	8	0	0	591 ± 82
Subfamily Salicornioideae				
SALICORNIEAE				
Allenrolfea occidentalis (S. Wats.) Kuntze[b]	9	0	0	525 ± 10
Salicornia bigelovii Torr.[b]	18[d]	0	0	361 ± 159
Salicornia maritima Wolff & Jefferies[b]	9	0	0	1107 ± 26
Sarcocornia utahensis (Tidestrom) A.J. Scott[b]	9	0	0	46 ± 5
Subfamily Salsoloideae				
SALSOLEAE				
Halogeton glomeratus (Bieb.) C.A. Mey.	9	0	0	170 ± 42
Salsola collina Pallas	9	100	106 ± 6	695 ± 77
Salsola tragus L. type A	136[c]	100	378 ± 26	
Salsola tragus type B	9[c]	100	—[e]	
Salsola tragus type C	9[c]	100	—[e]	
Salsola paulsenii Litv. lax	9[c]	100	—[e]	
Salsola paulsenii Litv. spinose	9[c]	100	—[e]	
Salsola soda L.	9[c]	22	0.2 ± 0.1[f]	232 ± 36
SARCOBATEAE				
Sarcobatus vermiculatus (Hook.) Torr.[b]	9	0	0	191 ± 46

(*continued on next page*)

Table 2 (*continued*)

Plant species[a]	No. plant replicates	Plants infested (%)	No. mites per infested test plant	
			Test plant (±SE)	Positive control (±SE)
SUAEDEAE				
Suaeda calceoliformis (Hook.) Moq.[b]	5	0	0	206 ± 52
Suaeda moquinii (Torrey) E. Greene[b]	18[d]	11	0.5 ± 0.4[f]	748 ± 114
Subfamily Polycnemoideae				
Nitrophila occidentalis (Moq.) S. Wats.[b]	9	0	0	657 ± 85
Family Amaranthaceae				
Subfamily Amaranthoideae				
AMARANTHEAE				
Amaranthus hypochondriacus L.	9	0	0	706 ± 67
Amaranthus palmeri S. Wats.[b]	9	0	0	850 ± 88
Amaranthus pumilus Raf.[b]	9	0	0	67 ± 15
CELOSIEAE				
Celosia huttoni Mast.	10	0	0	608 ± 63
Subfamily Gomphrenoideae				
GOMPHRENEAE				
Gomphrena globosa L.	9	44	0.6 ± 0.2[f]	175 ± 52
Family Aizoaceae				
Sesuvium verrucosum Raf.[b]	9	0	0	288 ± 62
Family Caryophyllaceae				
Arenaria hookeri Nutt.[b]	9	0	0	93 ± 21
Family Nyctaginaceae				
Abronia villosa S. Wats.[b]	9	0	0	670 ± 185

[a] Tribes are printed in all capital letters.
[b] Plant species native in North America.
[c] Plant cuttings were used instead of potted plants.
[d] Half were plant cuttings and half potted plants.
[e] Mite densities were not counted but were similar to those on *S. tragus* type A.
[f] All mites were dead, and there was no sign of feeding damage.

infested. Plants were measured, cut and air dried for 4 weeks at room temperature and weighed.

2.4. Statistical analysis

The data were analyzed using the statistical program SuperANOVA (version 1.11) on a Macintosh computer (Gagnon et al., 1989). Student's *t* test was used to test for differences between control and infested plants in the impact experiment.

3. Results and discussion

3.1. Host specificity

No live mites were found after 4 weeks on any of the nontarget test plants outside the genus *Salsola*, and none of the nontarget plants showed any sign of feeding damage (Table 2). All "positive control" cuttings of *S. tragus* type A were infested with high numbers of mites indicating that all the test plants were adequately challenged. *A. salsolae* successfully reproduced on *S. tragus* type A, type B, type C, *S. paulsenii* lax-form, *S. paulsenii* spinose-form, and *S. collina*, all of which are considered to be noxious weeds, and all of which are in the *Salsola* section *Kali* subsection *Kali* (Pyankov et al., 2001; Rilke, 1999). Numbers of mites on the other species of *Salsola* were not counted, because they were tested before the counting protocol had been developed. Other experiments and field observations in Europe reported that the mite attacks "*S. kali*" (de Lillo and Sobhian, 1996; Sobhian et al., 1999), but the plants may actually have been *S. tragus*, because of their geographic origins (Cay and Afyon, Turkey, which are inland, whereas *S. kali* is usually coastal (Mosyakin, 1996)). The mite could not reproduce on *Salsola soda* L. (in a different section, *Salsola* (Rilke, 1999)), *H. glomeratus* (same tribe, Salsoleae), *Suaeda calceoliformis* (Hook.) Moq. and *Suaeda moquinii* (Torr.) Greene (tribe Suaedeae, but same subfamily), or *Sarcobatus vermiculatus* (Hook.) Torr. (tribe Sarcobateae, but same subfamily) (Table 2). The small number of mites extracted from *S. soda*, *Su. moquinii*, and *Gomphrena globosa* L. all appeared to be dead. No mites were seen during the visual inspection of the plants that preceded mite extraction, and there were no signs of feeding damage on any of these plants. Either the mites were able to survive longer on some of these plants, or the cadavers remained on them because the plant structure was conducive to retaining them. Plants of *Su. moquinii* were tested over four different dates, and mites (eight and four individuals) were found on only two plants tested on one date. The absence of mites on the other three test dates, on a total of 16 plants, indicates that this mite does not usually remain or multiply on this plant species. No mites were found on any of the five *Su. calceoliformis* plants tested. *G. globosa* has a bushy inflorescence which may explain why mites were retained on this species; however, we never found more than one mite on a plant. Although *S. soda* has a glabrous surface, a fifth of the plants retained one mite. Even if mites found on these plants had been alive at the time of extraction, the results clearly show that there was no population increase on these nontarget plant species, particularly in comparison to the population growth observed on the positive controls.

On *S. tragus* cuttings, 3 weeks was sufficient time for the mite population to complete about two generations and for damage to meristematic tissue to become obvious (Fig. 1A). Mites had been observed to occasionally persist up to 3 weeks on young beet plants (with no signs of feeding), so a longer study period was used (at least 4 weeks) to avoid recording mites that had persisted in sheltered locations without feeding and to be sure that any signs of damage would be evident. This time interval is similar to what has been used for testing other species of *Aceria* mites (Craemer, 1995; Littlefield et al., 2000; Rosenthal and Platts, 1990; Sobhian et al., 1989, 2004). Because all the test plants were young and had meristematic tissue, they were considered to be at the most vulnerable developmental stage for attack.

Mite species in the genus *Aceria* generally have narrow host ranges, which are usually restricted at least to one plant genus or possibly a few closely related genera (Boczek and Petanovic, 1996; Briese and Cullen, 2001; Oldfield, 1996; Rosenthal, 1996). The majority attack only one host, and many are limited to species within a single genus. A few species have been reported to attack plants in two closely related genera (e.g., *Aceria malherbae* Nuzzaci on *Convolvulus* and *Calystegia* (Rosenthal and Platts, 1990)), and a few can attack host plants from more than one family (e.g., *Aceria tulipae* (K.) on tulip,

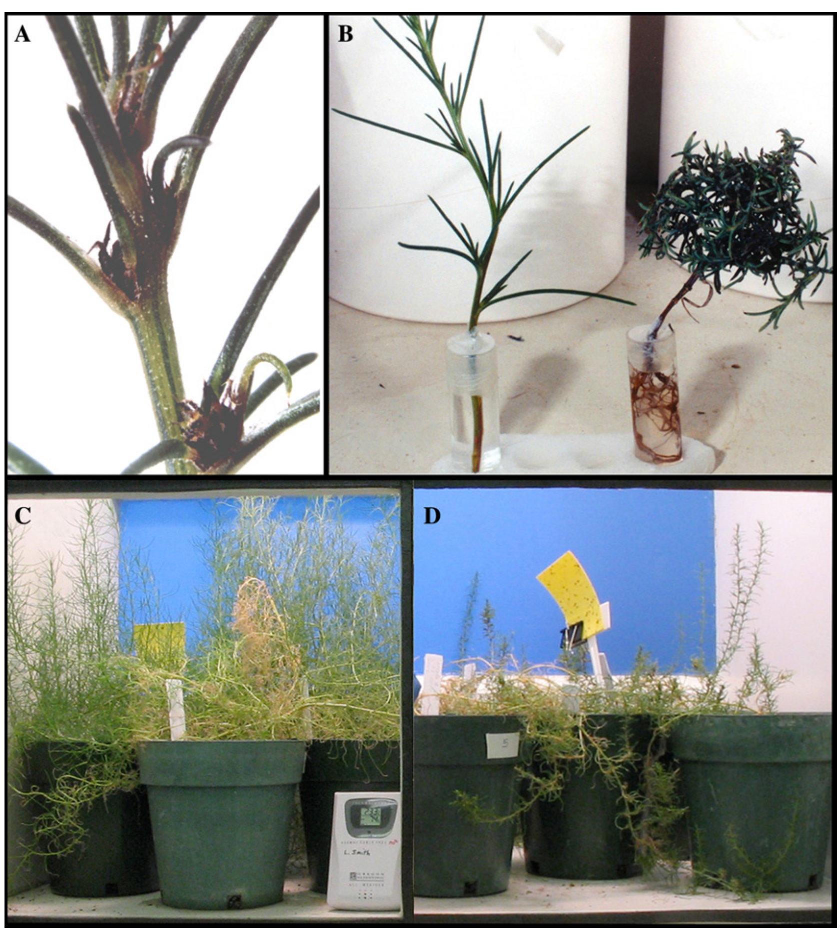

Fig. 1. (A) Damage to leaf meristems of *S. tragus* type A after exposure to *A. salsolae* mites for 3 weeks; (B) Comparison of uninfested greehouse cutting of *S. tragus* (left) to an severely stunted infested plant collected in Greece (right, C) Comparison of growth of uninfested *S. tragus* type A (left) to infested plants (right) 14 weeks after infestation by the mite *A. salsolae* (grown under artificial lights inside quarantine laboratory).

onion and grasses (Perring, 1996)). However, the *Aceria* species that attack monocots are considered to be evolutionarily very distant from those that attack dicots (Oldfield, 1996). *Aceria* species of economic importance attack many crops, including corn, tomato, carrot, sweet potato, and a variety of ornamental plants (Jeppson, 1975; Perring, 1996; Smith-Meyer, 1996).

The high degree of host plant specificity of *Aceria* and some of its close relatives has resulted in the successful use of several species for biological control of weeds (e.g., *Aculus hyperici* (Liro), *Eriophyes* (= *Aceria*) *chondrillae* (Canestrini), *Aceria malherbae*, and *Aceria acroptiloni* Shevtchencko and Kovalev) (Rosenthal, 1996). In the case of *A. salsolae*, it is able to feed and reproduce on only a few closely related species in the *Salsola* section *Kali* subsection *Kali* (Rilke, 1999), all of which are alien to North America and are noxious weeds.

3.2. Host plant impact

In the impact experiment, mite populations established on all of the infested *S. tragus* plants and signs of damage appeared within 4 weeks. The mite population increased exponentially during 37 weeks (Fig. 2), and the visual difference in plant size was very evident at 14 weeks (Fig. 1C). The number of axil nodes, measured at week 12, on infested plants per 2-cm-long branch tip was 2-fold higher on infested plants (8.6 ± 0.2 SE) than on uninfested plants (4.2 ± 0.4), which reflects the stunting effect of the mite (Student's t test; $P = 0.0001$). Infested plants (37.2 ± 4.5 cm) were 44% shorter than uninfested plants (66.8 ± 11.4 cm) at 25 weeks after infestation ($P = 0.04$), and based on the combined length of all branches, infested plants (353 ± 96 cm) were 66% smaller than uninfested plants (1051 ± 258 cm) ($P = 0.03$). The experiment was stopped at 37 weeks because some of the control plants had become infested. At this time, the biomass of "infested" plants (3.4 ± 1.0 g) was 59% less than that of the control plants (8.2 ± 2.5 g) but the difference was not significant due to the low sample size ($n = 4$; $P > 0.05$). None of the plants had started flowering, so no impact on seed production could be observed. The experimental light intensity (140 μmol/s PAR) was much lower than natural outdoor light (which is up to 1900 μmol/s), and the temperature and humidity were more moderate than typical outdoor conditions. So, the experimental plants tended to be lankier and less stiff than in the field. One control and one infested plant died between weeks 23 and 29. So far, we have not been able to grow plants to maturity in the confines of the mite quarantine room, which hampers our ability to measure impact on seed production. In the field in Europe, mites are found on dramatically stunted plants (Fig. 1B). In a field study in Afyon, Turkey, infested plants were less than half the size (13.4 cm tall) of uninfested plants (35 cm) at the end of August (Sobhian et al., 1999).

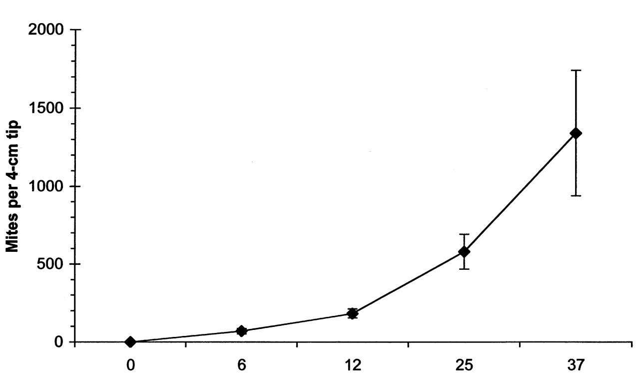

Fig. 2. Population growth of the mite, *A. salsolae*, on *S. tragus* type A plants (number per 4-cm branch tip, ±SE).

4. Conclusions

This mite did not multiply on or damage plants outside *Salsola* section *Kali* subsection *Kali* (which includes *S. collina*, *S. kali*, *S. tragus*, and *S. paulsenii*). Because there are no native North American or economic plants in this genus there is negligible risk that this mite will directly harm nontarget species. The mite is expected to decrease the size of *S. tragus*, which would reduce many of the weed's negative impacts, including: (1) likelihood of plant skeletons tumbling and cause less interference with automobile traffic, clogging of irrigation systems and pile-up on buildings and fencelines; (2) water consumption on fallow land, and (3) competition with other desirable vegetation. The mite would reduce biomass of Russian thistle available to other insect pests, but it is not known if it would further reduce the attractiveness or suitability of the plant to them. If the mite prevents Russian thistle from developing viable seed, then it would be expected to substantially further reduce population densities of the weed. This would reduce the need to apply herbicides to control the weed along rights-of-way, to cultivate fallow dryland fields, and to apply insecticides to control vectors of curly top virus harboring on Russian thistle.

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